



# Influence of high density planting and spatial arrangement on growth and development in *Musa* AAA Simmonds

## Influencia de altas densidades de siembra y distribución espacial sobre el crecimiento y desarrollo en *Musa* AAA Simmonds

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### ABSTRACT

Banana is after apple, the most consumed fruit in the world for its nutritional contribution. Given its importance, it is necessary to advance in the development of agronomic management strategies that contribute to increase productivity and offer alternatives to regulate the consequences derived from the seasonality of production in the Urabá area (Colombia). For this, the clone Williams (*Musa* AAA Simmonds), at different planting densities (2000, 2500, 3000 and 3500 plants ha<sup>-1</sup>), different population arrangements (triangle, rectangle and double furrow), compared with a relative control (1700 plants ha<sup>-1</sup> in triangle) was evaluated. The design used was randomized complete blocks in factorial arrangement of 4 x 3 + 1 (densities x arrays + control). The variables height and perimeter of the pseudostem, number of leaves from planting to harvest, leaf

area index (IAF), light extinction coefficient, number of suckers and developmental stages (days elapsed after flowering and harvest) were determined. An analysis of general variance was carried out and another one excluding the control. The Tukey test (P <0.05) was applied to the qualitative variables and contrasts of orthogonal polynomials were made to test the linear and quadratic effects of the population density factor. The results indicated that the high planting densities and the population arrangements had a negative effect on the perimeter of the pseudostem and the height of the main sucker, favored the LAI, influenced the extinction coefficient, but did not affect the development of the plants.

**Keywords:** Banana; Light interception; Plant competition; Plant population.

## RESUMEN

El banano es después de la manzana la fruta más consumida en el mundo, por su aporte nutricional. Dada su importancia, se requiere avanzar en el desarrollo de estrategias de manejo agronómico, que contribuyan a incrementar la productividad y ofrezcan alternativas para regular las consecuencias derivadas de la estacionalidad de la producción, en la zona del Urabá (Colombia). Para ello, se evaluaron en el clon Williams (Musa AAA Simmonds), diferentes densidades de plantación (2.000, 2.500, 3.000 y 3.500 plantas ha<sup>-1</sup>), distintos arreglos poblacionales (triángulo, rectángulo y doble surco) y un testigo relativo (1.700 plantas ha<sup>-1</sup> en triángulo). El diseño utilizado fue de bloques completos al azar en arreglo factorial, de 4 x 3 + 1 (densidades x arreglos + testigo). Se determinaron la altura y perímetro del pseudotallo, el número de hojas de siembra a cosecha, el índice de área foliar (IAF), el coeficiente de extinción de luz, el número de hijos y fases de desarrollo: días transcurridos a floración y cosecha. Se realizó un análisis de varianza general y otro excluyendo el testigo. Se aplicó la prueba de Tukey (P<0,05) a las variables cualitativas y se hicieron contrastes de polinomios ortogonales, para probar los efectos lineal y cuadrático del factor densidad de población. Los resultados indicaron que las altas densidades de plantación y los arreglos poblacionales tuvieron un efecto negativo sobre el perímetro del pseudotallo y la altura del hijo a parición, favorecieron el IAF, influyeron en el coeficiente de extinción, pero no afectaron el desarrollo de las plantas.

Palabras clave: Banano; Interceptación de luz; Competencia de plantas; Población de plantas.

## INTRODUCTION

Banana is the most widely consumed tropical fruit of the world. Colombia ranks fourth among the exporting countries with 1,806,000 thousands of tons (Biswas & Kumar, 2010; FAO, 2019); furthermore, it ranks third among the agricultural products most exported by Colombia after coffee and flowers (AUGURA, 2019). Banana yield in the Uraba region is dominated by climate seasonality, which determines two well-defined periods: A dry and productively limited first semester, followed by a rainy and oversupplied second semester (Toro *et al.* 2016). This, in turn, affects the behavior of international prices, which follow an inverse trend to that of fruit production (AUGURA, 2012), thus putting traditional banana production systems in disadvantage.

Establishing high density (HD) banana plantations is a cultivation practice that allows not only to increase productivity without affecting fruit quality, but also optimizing the use of natural resources (Gogoi *et al.* 2015; Hanuman Naik *et al.* 2016c); furthermore, the capacity of the culture system to suppress common weeds from tropical regions (Lanza *et al.* 2017) and reduce the severity of black Sigatoka disease, caused by *Mycosphaerella fijiensis* (Barrera *et al.* 2016) is added. However, larger plant numbers take a toll on both light interception (as also affected by leaf area) and the passage of light through the canopy. This can be assessed through the light extinction coefficient ( $k$ ), which usually ranges from 0.45 to 0.75, thus constituting an indicator

of light supply inside the production system (Stover, 1984). Densities above 5000 plants ha<sup>-1</sup> usually determine intensities of 2500 lux, while 2500 plants ha<sup>-1</sup> register 7200 average lux counts (Debnath *et al.* 2015). Leaf Area Index (LAI) being directly proportional to planting density (Rodríguez *et al.* 2007), values of 3.36 in this parameter are associated to 2500 plants ha<sup>-1</sup>, while records of 6.11 correspond to 6666 plants ha<sup>-1</sup>, which exerts a negative effect on the plantation already (Debnath *et al.* 2015).

Although Lecompte & Pagès (2007) reported that shading reduced the number of primary roots derived from the corm by 12%, they found no effect on the elongation rate, but on the density and diameter of the first order lateral roots, which were reduced by 32% and 14%, respectively. Likewise, morphology, growth and productivity can be affected by varying photonic flow gradients (Siles *et al.* 2013). In addition, there is evidence that shading is positively related to leaf emission rate, leaf area, pseudostem perimeter and height, while fruit weight and quality are negatively affected (Sarrwy *et al.* 2012). In this same regard, however, Mustafa & Kumar (2012) report 120 t ha<sup>-1</sup> yields of good fruit quality at 4091 plants ha<sup>-1</sup> (which is considered to be HD as also confirmed by Mahmoud (2013).

Considering the importance of banana cultivation and the need to make better use of the soil through larger plant populations, the current study intends to validate this alternative by evaluating its effect on the growth and development of the clone Williams established under different densities and spatial distributions.

## MATERIALS AND METHODS

Research was conducted from 2015 to 2016 at *La Tagua* farm, which belongs to the company Bananeras de Urabá, located in the municipality of Turbo, Antioquia (Colombia). The experimental site is located at 07°53'N 76°41'O, with an average temperature of 27°C, 28 m asl, 85-90% relative humidity and average annual rainfall of 2700 mm. All these features correspond to a very humid tropical forest climate (Belda *et al.* 2014). The soil exhibited clay loamy texture; pH 5.8; organic matter (OM) content, 1.73%; respective Ca and Mg levels of 8.9 and 4.11 cmolckg<sup>-1</sup>; K, 0.41 cmolckg<sup>-1</sup>; P, 21.4 mg kg<sup>-1</sup>; S, 5.67 mg kg<sup>-1</sup>; Zn, 2.0 mg kg<sup>-1</sup>; B, 0.54 mg kg<sup>-1</sup>; Cation Exchange Capacity (CEC), 13.6 cmolckg<sup>-1</sup>; and an adequate relationship between bases. This information allowed defining the nutrition plan to meet the needs of the plantation, which was set up with *in vitro* propagated seedlings of the clone Williams (*Musa* AAA Simmonds), distributed according to the treatment plan (Table 1). Initial soil organic matter and P supplies conformed to crop requirements and soil analysis. The subsequent agronomic management was done according to the technical recommendations for each particular case.

The study was conducted under a randomized complete block design with 4 x 3 (four planting densities x three population arrangements) bifactorial arrangement, plus a control treatment, with three replicates per treatment. This resulted in 13 treatments featured by the combinations between the four planting densities

Table 1. Treatments, planting densities and spatial arrangements in a banana plantation of the clone Williams (*Musa* AAA Simmonds).

Treatment	Planting density (plants ha <sup>-1</sup> )	Spatial arrangements (m)
1	1700	Control (2.7 x 2.7)
2	2000	Triangle (2.3 x 2.3)
4	2500	Triangle (2.15 x 2.15)
5	3000	Triangle (1.95 x 1.95)
6	3500	Triangle (1.8 x 1.8)
7	2000	Rectangle (3.2 x 1.57)
8	2500	Rectangle (2.8 x 1.30)
9	3000	Rectangle (2.6 x 1.20)
10	3500	Rectangle (2.4 x 1.15)
11	2000	Double row (dp* 1.0 x dr** 3.3)
11	2500	Double row (dp* 1.2 x dr** 3.3)
12	3000	Double row (dp 1.0 x dr 3.0)
13	3500	Double row (dp 1.0 x dr 2.8)

\* dp distance between plants (m), \*\* dr distance between rows (m).

(2000, 2500, 3000 and 3500 plants ha<sup>-1</sup>) and the three arrangements (triangle, rectangle and double furrow), plus the relative control (1700 plants ha<sup>-1</sup> under a triangular arrangement). Each experimental unit contained an approximate population of 26 plants of which we established the “useful plot” (four central plants). Growth and development variables were assessed following homonymous methodology as defined by Martínez & Cayón (2011) for the clones Great Dwarf and Valery.

**Plant height and pseudostem perimeter (m).** Plant height was measured from the base at the junction of the corm with the pseudostem to the armpit of the last leaf. The circumference was taken at 1m, height from the ground at the time of harvest.

**Number of leaves to harvest (No).** The total number of leaves produced by the plant was counted both at flowering and harvest.

**Leaf area (cm<sup>2</sup>).** This parameter was estimated as the product of leaf length, maximum width and the constant 0.876 (Cogliatti *et al.* 2010). The average foliar area of a leaf was multiplied by the number of leaves present on the plant, during flowering.

**Leaf area index (LAI).** It was calculated following methodology by Barrera *et al.* (2010), based on foliar area and planting distance, during the flowering period of the crop.

**Light extinction coefficient (k).** This value was assessed at each stratum (1 m above the ground and at the middle and upper layers of the foliage), in the development phases floral differentiation, flowering and harvest, following the model of Monsi and Saeki for continuous canopies, which is based on the Lambert-Beer Law (Cabezas & Corchuelo, 2005).

**Floral differentiation (days).** This is a time measurement which goes from the moment of planting to that of floral differentiation, when the basal lobes of the leaf flag are asymmetric.

**Flowering (days).** Time elapsed from the production of the first true leaf (*i.e.*, the one that already exhibits the morphological characteristics of the clone) to the emergence of the inflorescence.

**Harvest (days).** Time elapsed from the moment of the emergence of the inflorescence to the harvest of the fruit bunch.

An overall analysis of variance was performed for all treatments in order to determine their effects on the studied variables. An additional analysis of variance contemplated only the two factors in question (densities and population arrangements), in order to both determine their individual effects on the variables and assess their interactions. Orthogonal polynomial contrasts were also performed to test the linear and quadratic effects of the planting density factor. In addition, polynomial regression models were tested on all treatments, including the control one, in order to estimate the best fit. A Tukey test at 5% was applied to the spatial arrangement factor, since it is qualitative in nature, and thus exhibits no group structure.

## RESULTS AND DISCUSSION

**Growth.** The analysis of variance (both including and excluding the control treatment) reported significant effects of planting density and spatial arrangement on the studied growth parameters of the clone Williams. The variables not were affected by the treatments and no significant effect resulted from the interaction between arrangement A and planting density B. The Tukey test ( $p \leq 0.05$ ) revealed that pseudostem perimeter, sucker height at flower shoot

emergence, LAI and number of leaves at harvest were significantly influenced by the treatments (Table 2).

The response of pseudostem perimeter to planting density fits a quadratic regression model ( $R^2 = 0.99$ ). The values of this parameter peaked at low densities (2000 plants  $ha^{-1}$ ) and decreased notably at HD (Figure 1a). The development of this organ is affected by HD through competition between plants, which induces a photomorphogenic action on the part of photoreceptors such as phytochromes, cryptochromes and phototropins (Franklin, 2016). Regarding the thickness of the pseudostem, it is important to highlight its strong association with the vigor and productivity of banana plants (Kumar & Pandey, 2010). In addition, the root system is reduced by increasing planting densities (Lecompte & Pagès, 2007; Chaudhuri & Baruah, 2010), which affects nutrient absorption and plant anchoring (Mustafa & Kumar, 2012). Pseudostem thickness reduction with increased planting density has also been attributed to competition for light and soil nutrients (Chaudhuri & Baruah, 2010). More recently, Patel *et al.* (2018) found significant effects on the height of the pseudostem by providing nutrients and greater spacing between the banana plants cv. Grand Naine. Nonetheless, Delgado *et al.* (2008) and Smith *et al.* (2010) did not find significant effects after conducting similar studies in other commercial musaceae planted at densities of 2500 plants  $ha^{-1}$ .

As to the number of leaves at harvest, the highest count (9.0 leaves  $plant^{-1}$ ) was recorded under the triangular arrangement, thus

exceeding by 9.7% the record of the double row arrangement, which was 8.3 leaves  $plant^{-1}$ . For its part, the rectangular arrangement (8.5 leaves  $plant^{-1}$ ) did not differ from the triangular and double row arrangements (Figure 1b). In analyzing the spatial arrangements under each planting density, the highest number of leaves corresponded to 3000 plants  $ha^{-1}$  under the triangular arrangement (9.0 leaves  $plant^{-1}$ ), which exceeded by 30.3% the record of the 2500 plants  $ha^{-1}$  density under the rectangular arrangement. The rest of the treatments did not differ from the triangular arrangement (Table 2). The triangular arrangement is likely to favor the spatial distribution of the leaves, thus allowing greater light uptake (Chaudhuri & Baruah, 2010). These authors attributed larger numbers of leaves at flower shoot emergence and harvest under low planting densities to better exposure to light.

Main sucker height at flower shoot emergence as a function of planting density was partially explained by a quadratic regression model ( $R^2 = 0.42$ ), wherein the maximum records corresponded to the lowest planting densities (about 2000 plants  $ha^{-1}$ ), the increase of which determined a reduction in the parameter (Figure 1a). According to the means test, maximum main sucker height was recorded at a density of 2500 plants  $ha^{-1}$  under the double furrow arrangement (111.22 cm), followed by 2500 and 3000 plants  $ha^{-1}$  under the triangular arrangement, and by 3500 plants  $ha^{-1}$  under the rectangular one, both of which behaved similarly by reaching an average height of 21.79 cm. The rest of the treatments were statistically similar to the control treatment.

Table 2. Effect of planting density and spatial arrangement on the growth of banana clone Williams (*Musa* AAA Simmonds).

Treatment	Spatial arrangement	Planting density (plants $ha^{-1}$ )	PH	NLPH	MSHFSE	LAI	$k$
1	Triangle	1700	200.4c	8.89 ab	51.67 ab	1.83 d	0.55 b
2	Triangle	2000	225.8 ab	8.55 ab	73.78 ab	2.09 bcd	0.85 a
3	Triangle	2500	210.6 abc	9.44 ab	20.22 b	2.03 cd	0.81a
4	Triangle	3000	208.1 bc	9.55 a	20.93 b	3,29 bcd	0.68 ab
5	Triangle	3500	212.9 abc	8.67 ab	62.50 ab	3.62 ab	0.67 ab
6	Rectangle	2000	229.8 ab	8.44 ab	51.83 ab	2.42 bcd	0.55 b
7	Rectangle	2500	213.6 abc	7.33 b	80.66 ab	2.61 bcd	0.62 ab
8	Rectangle	3000	219.1 abc	9.33 ab	35.67 ab	3,34 abcd	0.53 b
9	Rectangle	3500	231.9 ab	8.78 ab	24.22 b	4.34 a	0.75 ab
10	Double row	2000	216.6 abc	8.34 ab	40.22 ab	2.04 cd	0.58 b
11	Double row	2500	234.7 a	8.22 ab	111.22 a	2.71 bcd	0.53 b
12	Double row	3000	222.4 abc	8.00 ab	49.00 ab	3.52 abc	0.67 ab
13	Double row	3500	227.4 ab	8.44 ab	37.89 ab	3.50 abc	0.63 ab

Numbers with the same letters do not differ statistically according to the Tukey test ( $p = 0.05$ ).

PH = Plant height at flowering; NLPH = Number of leaves at harvest; MSHFSE = Main sucker height at flower shoot emergence; LAI = Leaf area index,  $k$  = Light extinction coefficient at flowering.

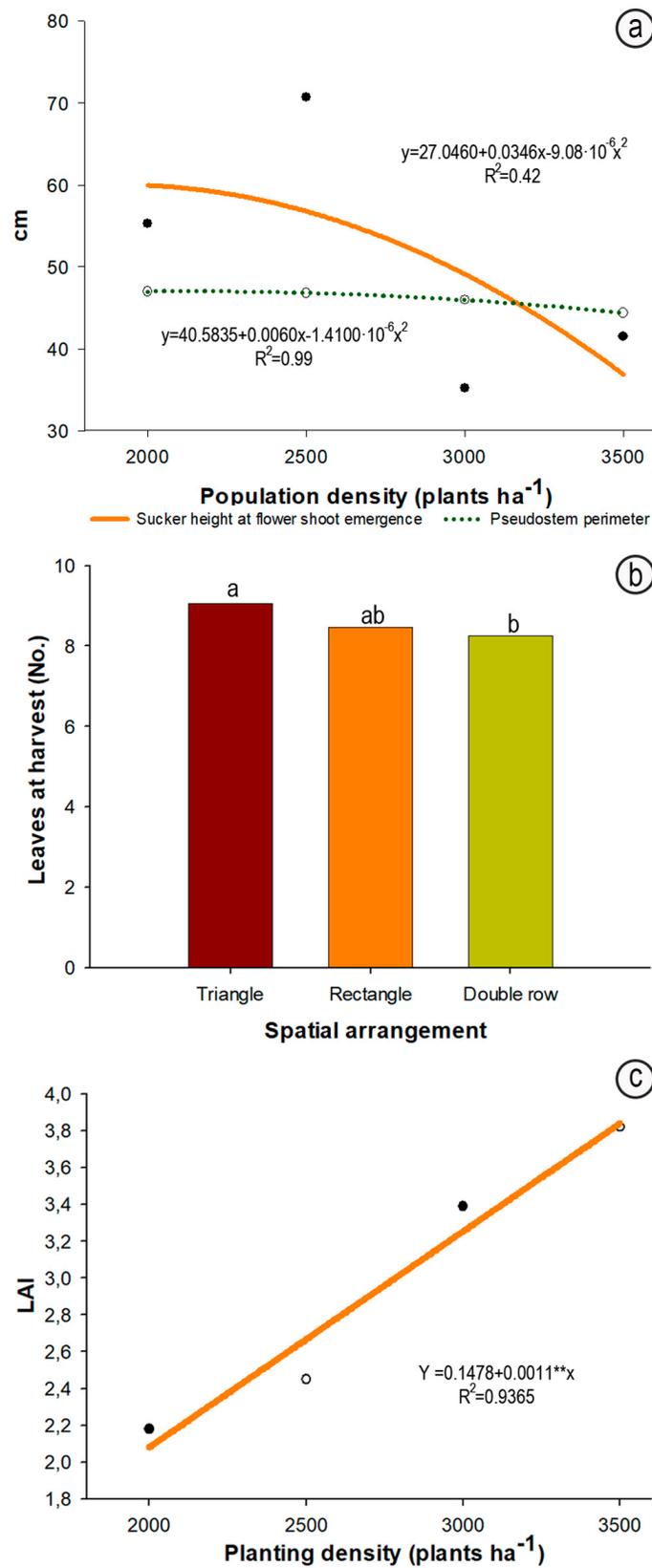


Figure 1. Response variables to different planting densities in the banana clone Williams (*Musa* AAA Simmonds). a) Pseudostem perimeter (Significant differences at 10% ( $p = 0.05-0.10$ );  $R^2$ : Coefficient of determination); b) Number of leaves (Mean values with the same letters do not differ statistically according to Tukey's test ( $p=0.05$ )); c) Leaf area index -LAI.

This parameter is essential to decide on the appropriate density when trying to establish the crop in consecutive production cycles. The results obtained in this study for densities below 2500 plants ha<sup>-1</sup> could be of interest to establish the optimum density when using the method of several consecutive cycles.

Our analyses would suggest that in the environmental conditions of the Urabá, the cultivation system in HD at a second cycle is feasible, because the effect of the treatments, despite presenting statistical differences in the height of the return sucker, this is adequate, as long as the price opportunities in the market are competitive, or the fruit is used to win quotas for exporting boxes, since the same number of boxes delivered in the first semester (good price), is received in the second semester, with the same commercial value and number of boxes, because as plantation density increases, it contributes to increasing productivity per hectare (Barrera *et al.* 2020). These results are harmony with those obtained by Chaudhuri & Baruah (2010) who found that planting density significantly affected both the number of suckers and their production. This can be attributed to incident radiation, especially for the 3000 plants ha<sup>-1</sup> density under the triangular arrangement. However, most of the treatments exhibited a similar behavior to that of the control (Table 2). In this respect, Stover (1984) reports that an optimum range for sucker development is 14-16% of the photosynthetically active radiation entering the plantation. Likewise, the vegetative growth of banana plants in terms of pseudostem height and circumference is positively influenced by reduced planting distances (Palkar *et al.* 2012), mainly due to mutual shading, which affects growth rate through competition for light (Gliessman, 1998; Nalina *et al.* 2000).

LAI correlated directly with planting density, as explained by the linear regression model ( $R^2 = 0.96$ ) fit by the relation between these parameters (Figure 1c), which is consistent with the results of Chaudhuri & Baruah (2010). The highest LAI value (4.34) was obtained with the 3500 plants ha<sup>-1</sup> density under the rectangular

array, followed by that of the 3500 plants ha<sup>-1</sup> density under the triangular arrangement. For its part, the lowest LAI value was registered by the control treatment (Table 2). The current LAI values are similar to the 3.49 record found by Rodríguez *et al.* (2007) for the Great Dwarf clone, exception made of their 3500 plants ha<sup>-1</sup> density record under a rectangular arrangement. On the other hand, the elevated LAI values observed for the 3500 plants ha<sup>-1</sup> density under the rectangular arrangement can overcome the optimal LAI threshold. Under these conditions, 90% of the incident radiation is intercepted by the canopy (Turner *et al.* 2007), which is scarcely beneficial for the plant and tends to hinder its productivity. However, in the opinion of Smith *et al.* (2010), this situation is likely to increase unit area yield.

The light extinction coefficient ( $k$ ) was influenced by both planting density and spatial arrangement (Table 2 and Figure 2). With the exception of the 2000 and 2500 plants ha<sup>-1</sup> densities under the triangular arrangement, all other treatments registered values within the 0.45 to 0.75 range, as previously reported for banana by Stover (1984). The value of  $k$  depends on plant architecture and leaf position, angle and orientation (Chaves *et al.* 2009). The differences observed in the current study confirm the influence of the plantation system, in agreement with Pilau & Angelocci (2015). However, it should be noted that the reduction in the value of  $k$  does not necessarily increase productivity, under the assumption that the photosynthetic capacity is also increased. This is so because the latter also depends on other factors such as sink force, CO<sub>2</sub> availability, leaf – sink distance, leaf age and stressing situations (Guevara & Rodríguez, 2006).

The development-related variables, namely days to flower differentiation (DFD), days to flowering (DF), and days from flowering to harvest (DFH) were not influenced ( $P > 0.05$ ) by planting arrangement, planting density or their interaction. The results confirm that the evaluated densities and arrangements did

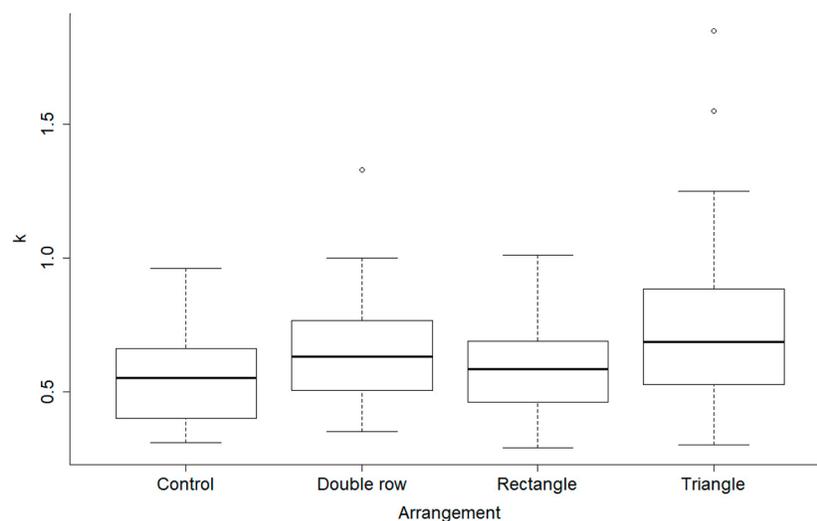


Figure 2. Influence of spatial arrangement on the light extinction coefficient in banana clone Williams (*Musa* AAA Simmonds).

not compromise the length of the growing period or the duration of the studied plant development stages, namely DTF, FT and HT. In this regard, the average vegetative cycle of the banana crop in the evaluated arrangements was 219, 304, 307 and 308 days for the control, triangular, rectangular and double furrow arrangements, respectively, at all the evaluated planting densities (Figure 3). About this aspect, Martínez & Cayón (2011) recorded similar data for the clone Gran Enano in the Urabá Antioqueño region (i.e., the Urabá region of the Department of Antioquia, Colombia). However,

those data are different from those indicated by Chaudhuri & Baruah (2010) and Hanuman Naik *et al.* (2016a; b), which showed significant effects of high planting densities on crop development and new succession buds. These results are important because in the event of an extension of the reproductive cycle, the production costs would also rise through increased agricultural labor and a more expensive phytosanitary control of *Mycosphaerella fijiensis*, for which a higher number of fungicide application cycles would be necessary.

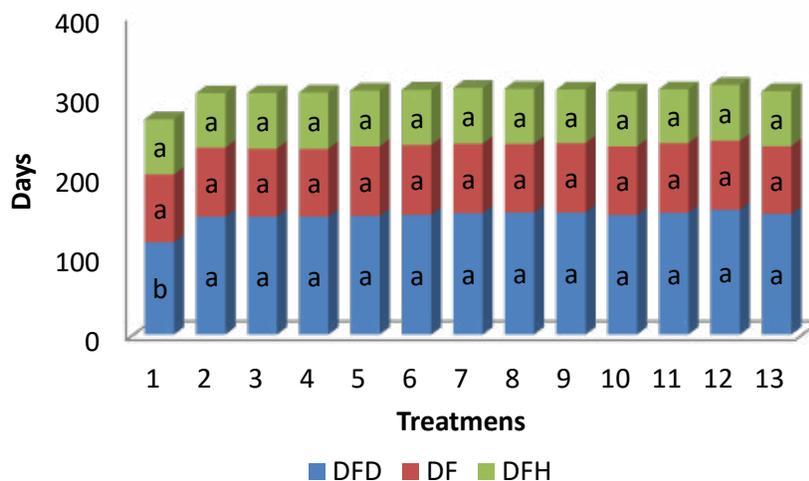


Figure 3. Development phases of the banana clone Williams (*Musa* AAA Simmonds), in different planting densities and population arrangements. DFD: days to flower differentiation. DF: days to flowering. DFH: days from flowering to harvest. Mean values with the same letters do not differ statistically according to Tukey's test ( $p=0.05$ ).

In conclusion, the pseudostem perimeter and main sucker height at the time of flower shoot emergence were negatively affected by increased planting densities under the different spatial arrangements studied in this research and the triangular spatial arrangement was found to increase the number of leaves at harvest, while the double row arrangement reduced this parameter. In the same way, the leaf area index showed a direct correlation with planting density, which, in turn, modified the light extinction coefficient inside the canopy. And finally, neither high planting density nor spatial arrangement influenced the duration of the phenological stages of the studied banana crop.

**Conflicts of interest:** The manuscript was prepared and reviewed with the participation of all the authors, who declare that no conflict of interest that threatens the validity of the results presented.

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